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Analysis of Sheet Metal Formability Studies of Friction Stir Processed Mg AZ31B Alloy using Response Surface Methodology

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Abstract

Weight reduction of the automotive components is one of the major goals of engineering design and manufacturing so that materials, energy, and costs are saved and environmental damage is reduced by reducing the overall weight of the vehicle. Magnesium alloys provide the solution for weight reduction as they have a high strength to weight ratio and can contribute to the overall weight reduction of the vehicle. Over the past few years, many researchers have tried to shape these alloys using various forming techniques. These studies have indicated that it is difficult to improve the room temperature formability of these alloys without deteriorating its strength. In this present work, a severe plastic deformation technique namely friction stir processing (FSP), which provides severe plastic deformation along with higher strain rates, than the conventional methods like ECAP, HPT, ARB etc, has been utilized for microstructural modification of the magnesium AZ31B alloy, thereby improving mechanical properties and formability of the material. In this present work, sheets of Mg alloys were processed under various combinations of rotational speed, traverse speed and tool tilt angle as per the selected experimental design. The total elongation of the friction stir processed sheets were measured from the tensile tests and the results were modelled using Response Surface Methodology's (RSM) Box Behnhen Design and the response equation and response plots were drawn and various conclusions were made.

Keywords: Friction stir Processing; MgAZ31B alloy; RSM

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1. Introduction

Magnesium alloys have great potential in the fields of automobile, aerospace and consumer electronic industries due to their high specific strength, high specific stiffness, excellent castability, and high electromagnetic shielding. However, these alloys exhibit low ductility at room temperature due to limited number of slip systems available in the hexagonal closed packed (hcp) structure [1-2]. Literature indicates that mechanical properties and formability can be improved by increasing grain size strengthening efficiency through grain refinement in Mg alloys [3-6]. Hence, in recent years, much research is focussed on microstructural modifications of magnesium alloys in order to enhance the mechanical properties [7-11].

Recently, friction stir processing (FSP) has been developed on the principles of friction stir welding (FSW) as an effective and efficient new method for grain refinement through microstructural modification, providing intense plastic deformation as well as higher strain rates than other methods. FSP produces equiaxed homogeneous microstructure consisting of fine grains, resulting in enhancement of mechanical properties the material.

2. Experimental Part

Fig.1. Friction stir processing set up

In this investigation, rolled sheet of magnesium AZ31B alloy, supplied by Xi'an Yuchen Metal Products Co., Ltd, China was used as the base material. The composition and mechanical properties of the base material are given in Table 1 and Table 2, respectively. The sheet of 4 mm thickness was cut into the required size (150 x100 mm) using milling machine. The friction stir processing was done on the vertical head milling machine with the position of the tool fixed relative to the surface of the sheet as shown in Fig.1. The work piece was firmly clamped to the bed and a specially made tool was plunged in to the selected area of the material sheet for sufficient time in order to plasticize the material around the pin. After adequate plasticization, the tool was traversed across the surface of the material for a single pass. The entire sheet was processed with 7-8 passes. A non consumable taper threaded tool made of high carbon steel, H13 with a shoulder diameter of 18 mm, pin diameter of 6 mm, and a pin length of 3 mm was used.

Table 1 Chemical composition of Mg AZ 31B-O (wt %)

Element	Al	Zn	Mn	Si	Ni	Fe	Mg
% Wt	3.02	0.89	0.29	0.026	.0009	0.0025	Balance

Table 2 Mechanical properties of as received material

Yield strength (MPa)	Ultimatetensile strength (MPa)	Elongation (%)	Hardness Kg/mm^2	Impact energy (J)
163	210	6.93	79	4

The room temperature tensile properties of the base and the friction stir processed sheet were evaluated by conducting tensile test on a 60 ton universal testing machine. Three tensile specimens were tested and the average of results is used for analysis. The tensile samples were cut along the processing direction as per ASTM E8M-04 guidelines.

3. Design of Experiments

Design of experiments is a powerful analysis tool analyzing the influence of process variables over some specific variable, which is an unknown function of these process variables. It is the process of planning the experiments so that appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions. Statistical approval to experimental design is necessary if we wish to draw meaningful conclusions from the data. [11].

4. Response Surface Methodology (RSM)

RSM is a collection of statistical and mathematical methods that are useful for modeling and analyzing engineering problems. In this technique, the main objective is to optimize the response surface that is influenced by various process parameters. RSM also quantifies the relationship between the controllable input parameters and the obtained response surfaces [11-12]. The design procedure of RSM is as follows [11].

1. Designing a series of experiments for adequate and reliable measurements of the response of interest.
2. Developing a mathematical model of the response surface with the best fittings.
3. Finding the optimal set of experimental parameters that produce a maximum or minimum value of response.
4. Representing the direct and interactive effects of the process parameters through two and three-dimensional plots.

5. Mathematical Model of elongation values

5.1 Response Equation for the elongation values

RSM's Box – Behnken design consisting of 17 experiments was conducted for developing the mathematical model for the elongation. The input parameters and their levels chosen for this work are given in Table 3. The final elongation results for the 17 experiments are given in Table 4.

Table 3 Input parameters and their levels

S.No	Parameter	Low Level	High Level
1	Rotational speed(RS)	900	1400
2	Welding Speed(WS)	24	40
3	Tool Tilt Angle(TA)	0	2

Table 4 Experimental layout for the Box-Behnken design

Run No	Rotational Speed, RS	Welding Speed, WS	Tool tilt angle, TA	Elongation (%)
1	0900	32	0	08
2	1150	24	0	08
3	1150	32	1	10
4	1150	32	1	10
5	1150	32	1	10
6	1150	32	1	10
7	1150	24	2	09
8	0900	32	2	09
9	1400	40	1	09
10	0900	24	1	07
11	0900	40	1	07
12	1400	32	2	10
13	1150	40	0	08
14	1150	40	2	09
15	1400	32	0	09
16	1400	24	1	08
17	1150	32	1	10

The response equation for final elongation so obtained is given by
Sqrt(Elongation) =-5.95134+7.12529E-003 * RS +0.28637 * WS +0.21862 * TA-3.63210E-007 * RS * WS-1.41869E-005* RS * TA -1.31286E-004 * WS * TA-2.85991E-006* RS^2 -4.41997E-003* WS^2 -0.061240 * TA^2

6.0 ANOVA and Respose Surface Graphs

The analysis of variance (ANOVA) was applied to study the effect of the input parameters on the elongation. The model summary statistics was done and it revealed that quadretic model is the best suggested model.So, for further analysis this model was used. ANOVA is commonly used to summarise the test for significance on individual model co-efficients.The value of "Prob > F" for the quadretic model is less than 0.0001 which indicates that the model terms are significant,.The Model F-value for the model is 39.56, which implies that the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Table 5. Regression statistics

Std. Dev.	Mean	C.V (%)	PRESS	R^2	Adj. R^2	Pred. R^2	Adeq Precision
5.532E-003	2.98	0.19	3.427E-003	0.9997	0.9993	0.9952	145.265

Table 5 gives the regression statistics. The co-efficient of determination R^2 is used to decide whether a regression model is appropriate. The co-efficient of determination R^2 provides an exact match if it is 1 and if the residual increases R^2 decreases in the range from 1 to 0. As the number of variables increases, the residual decreases, so that the co-efficient of determination R^2, increases its value. So, to obtain a more precise regression model judgment, co-efficient of determination R^2 adjusted for the degrees of freedom Adj. R^2 is used. Adj. R^2 is used for comparing the residual per unit degree of freedom. Adequate precision compares the range of the predicted values at the design points to the average prediction error. It is a measure of the signal to noise ratio. Ratio greater than 4 indicates adequate model discrimination. In this particular case, it is 145.265, which is well above 4. So the model can be used to navigate the response space. Further, it is seen that the R^2 value is 0.9997 and the Adj. R^2 is 0.9993. The predicted R^2 value of 0.9952 is in reasonable agreement with the Adj. R^2 value. The R^2 value in this case is high and close to 1, which is desirable [13].

The adequacy of the model has also been investigated by the examination of residuals [11]. The residuals, which are the difference between the respective observed responses and the predicted responses, are examined using the normal probability plots of the residuals and the plot of the residuals verses the predicted response. If the model is adequate, the points on the normal probability plots of the residuals should form a straight line. On the other hand, the plots of the residuals verses the predicted response should be structure less, that is, they should contain no obvious problem [13]. The normal probability plots of the residuals and the plots of the residuals verses the predicted responses for the final elongation values revealed that the residuals fall on a straight line implying that the errors are distributed normally. This implies that the model proposed is adequate and there is no reason to suspect any violation of the independence or constant variance assumptions [13]. Fig.2 gives the graph of the predicted verses actual data. It should fall on a straight line. The graph shows that the predicted verses actual data fall exactly one over the other implying that the prediction is correct. Figures 3-5 give the 3D surface graphs for the elongation values. As the model is adequate these 3D surface plots can be used for estimating the elongation values for any suitable combination of the input parameters namely the rotational speed, welding speed and tool tilt angle.

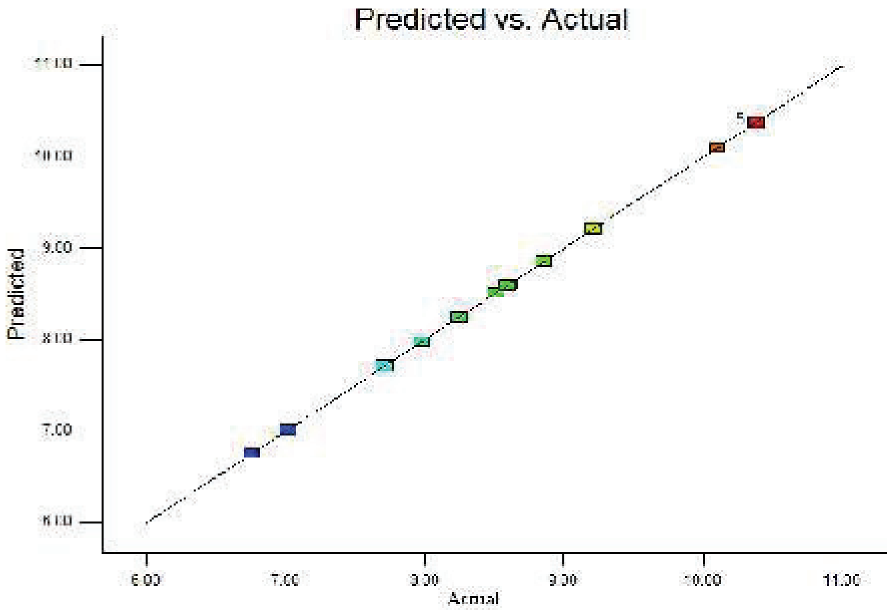

Fig. 2. Graph between the predicted value and the actual result

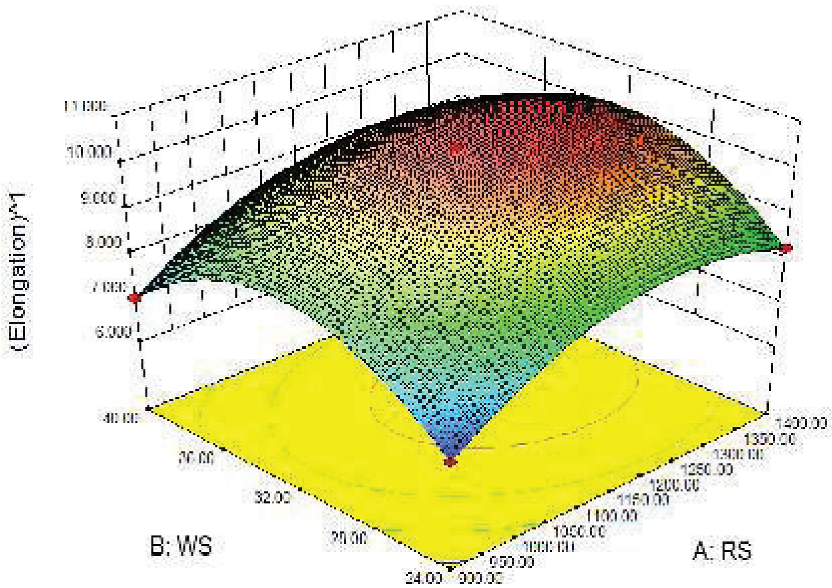

Fig. 3. 3D surface graph for the elongation values, as WS and RS varies.

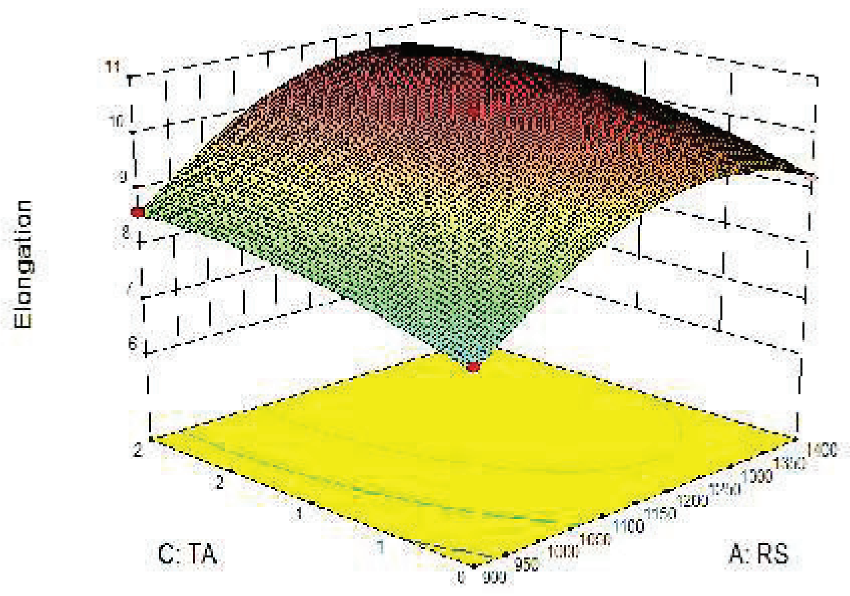

Fig. 4. 3D surface graph for the elongation values, as TA and RS varies

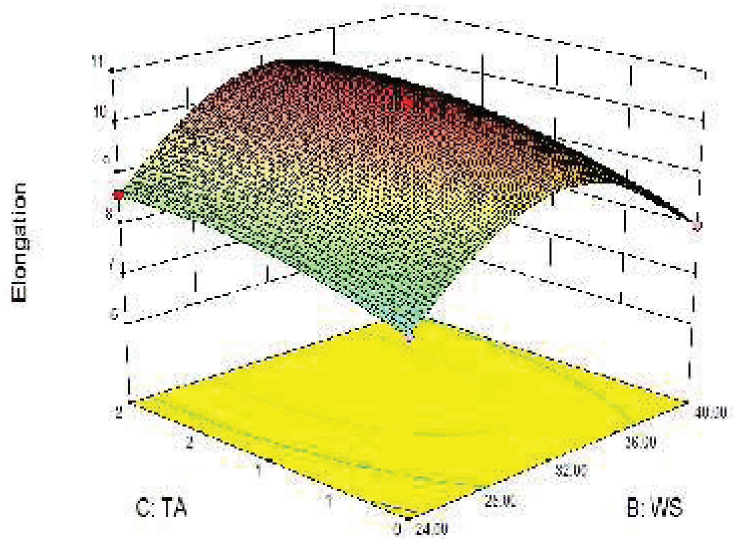

Fig. 5. 3D surface graph for the elongation values, as TA and WS varies.

7. Effect of process parameters on the response

A Box-Behnken design has been carried out to investigate the formability characteristics of friction stir processed AZ31B alloy. Fig. 2 gives the graph of the predicted verses actual data. It should fall on a straight line. The graph shows that the predicted verses actual data fall exactly one over the other implying that the prediction is correct. Fig. 3 is the 3D surface graph for the elongation values as WS and RS varies. It is seen from the graph that both rotational speed and welding speed have significant affect on the total elongation. At lower rotational speed (900 rpm), the amount of heat generation for softening the material is insufficient for complete deformation resulting in less formability. With increased rotational speed, formability (elongation) has been improved. The highest formability was obtained at a tool rotational speed of 1400 rpm and a welding speed of 32 mm/min.

Fig .4 shows the 3D surface graph for the elongation values, as TA and RS varies. It can be observed that the process parameters tool rotational speed (RS, rpm) and tilt angle (TA, degree) play a greater role during friction stir processing of magnesium alloys. From the experimental results, it is seen that as the rotational speed increases, the percentage of elongation increases due to increased heat input to the material for more refinement of grains. At a lower rotational speed (900 rpm), the results are lower because the heat required for softening the metal has not been achieved resulting in reduced refinement of grains. If the rotational speed is increased above 1150 rpm, the elongation decrease as higher rotational speeds (1400rpm) with lower welding speeds usually results in a higher temperature causing excessive grain growth, which subsequently leads to lower properties. According to the results, it is evident that as traverse speed increases percentage of elongation increases and then decreases. At lower traverse speed and highest traverse speed, percentage of elongation is observed to be lower. This is due to increased frictional heat and insufficient heat generated respectively. Also higher traverse speed produces poor plastic flow of the material due to poor disintegration at the metal interface. The properties of metal after friction stir processing were also affected from the tool tilt angle. The angle of 0^0 causes a serious problem of decreased elongation at lower rotational speeds due to insufficient forging pressure. The maximum elongation properties were obtained at 1150 rpm tool rotational speed with a traverse speed of 32mm/min and tilt angle of 2^0.Small tilt angle results in application of inclined force that can be resolved into horizontal and vertical components that aids in homogenization of material flow resulting better mechanical properties.

Fig. 5 shows the 3D surface graph for the elongation values, as TA and WS varies. In FSP, the tool rotational speed results in the stirring and mixing of the material around the rotating pin which in turn increases the temperature of the metal. It appears to be the most significant process variable since it tends to influence the transitional velocity. Intense plastic deformation during friction stir processing results in the generation of fine recrystallized grains that lead to improvement in the mechanical properties. However, the elongation did not change much with increase in the tool angle, even though its contribution in the stir processing is significant.

8. Conclusions

In this paper, the formability studies on friction stir processed AZ31B alloy has been studied and the total elongation of tensile tested samples cut from the friction stirred alloy has been taken to study its formability. The process has been modeled using Response Surface Methodology. An attempt has been made to determine the total elongation values of tensile tested samples of FSPed AZ31Mg alloy for various input parameters namely the rotational speed, welding speed and tool tilt angle. It has been found that all the three parameters have significant effect on the formability. The ANOVA performed and the various 3D graphs, and the prediction equation derived show that the total elongation values can be predicted very accurately.

References

[1] Aghion E, Bronfin B. Magnesium alloys development towards the 21st century. *Materials Science Forum* 2000; 19-30.

[2] Mordike B L, Ebert T. Magnesium: properties and applications –potential. *Materials science and Engineering A* 2001; **302**: 37-45.

[3] Yoshihara S, Nishimura H, Yamamoto H, Manabe KI. Formability enhancement in magnesium alloy stamping using a local heating and cooling technique. *Journal of Material processing Technology* 2003; **142:** 609-613.

[4] Zhang SH, Xu YC, Way ZT, Zhang QL, Palumbo G, Pinto S, Tricarico L. Formability and process conditions of magnesium alloy sheets, Magnesium Science, technology and applications. *Material Science Forum* 2005 ; **488-489**: 453-456.

[5] Zheng SH, Zhang K, ,Xua YC, Wang ZT, Xua Y, Way C. Deep drawing of magnesium alloy sheets at warm temperatures. *Journal of Material Processing Technology* 2007; **185**:47-151.

[6] Palumbo G, Sorgente D, Tricarico L Zhang SH, Zheng WT. Numerical and experimental investigations on the effect of heating strategy and the punch speed on the warm deep drawing of Mg alloy AZ 31. *Journal of Material Processing Technology* 2007; **191**: 342-346.

[7] J.A. del Valle, M.T. Perez-Prado, R.O. Ruano, Texture evolution during large-strain hot rolling of the Mg AZ61 alloy. *Mater.Sci. Eng. A* 2003; **355**:68-78.

[8] Lin HK, J.C. Huang, High Strain rate and / or Low Temperature Super Plasticity in AZ 31 Mg Alloys Processed by Simple High-Ratio Extrusion Methods. *Materials Transactions* 2002;**43**:2424-2432.

[9] Yamashita A, Horita Z, Langdon TG. Improving the mechanical properties of magnesium and a magnesium alloy through severe plastic deformation ,*Mater. Sci. Eng. A* 2001; **300:**142-147.

[10]Lin HK, Huang JC, Langdon TG. Relationship between texture and low temperature superplasticity in an extruded AZ31 Mg alloy processed by ECAP. *Mater. Sci. Eng A* 2005 **402**:250-257.

[11] Montgomery,C. *Design and Analysis of experiments*. 4th Edition, Wiley, New York, 1997.

[12] Jae-seob Kwak. Application of Taguchi and Response surface Methodologies for geometric error in surface grinding process. *International Journal of Machine Tool and Manufacturing* 2005; **45**:327-334.

[13] Noordin MY, Venkatesh V C, Sharif S, Elting S, Abdullah A. Application of Response Surface Methodology in describing the performance of coated carbide tools when turning AISI 1045 steel. *Journal of Materials Processing Technology* 2004; **145**:46-58.